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Chemical Engineers' Handbook

FIFTH EDITION

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INTERNATIONAL STUDENT EDITION

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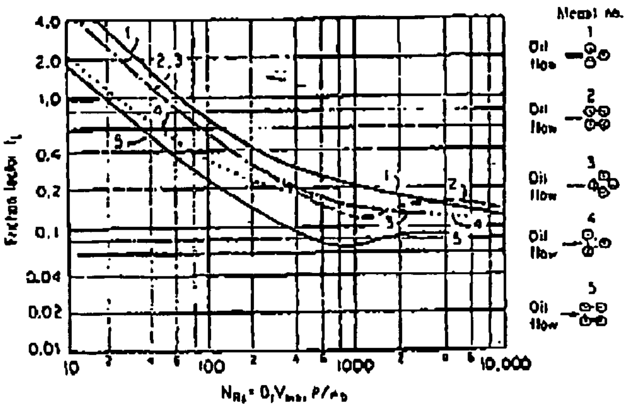

FIG. 5-68. Friction factors for transition-region flow across tube banks. [*From Bergelin, Brown, and Doberstein, Trans. Am. Soc. Mech. Engrs.*, 74, 953 (1952).] (Pitch is the minimum center-to-center tube spacing.)

Model	Rows	D_t, in.	Pitch/D_t
1	10	¾	1.25
2	10	¾	1.25
3	14	¾	1.25
4	10	¾	1.50
5	10	¾	1.50

$$m = \frac{0.57}{(N_{Re})_v^{0.25}} \qquad (5\text{-}167)$$

where $(N_{Re})_v = D_v V_{max}\rho/\mu$, dimensionless; D_v = volumetric hydraulic diameter [(4 × free-bundle volume)/(exposed surface area of tubes)], ft.; P = pitch (= a for in-line arrangements, = b or c, whichever is smaller, for staggered arrangement), ft.; other quantities as defined following Eq. (5-165). Bergelin *et al.* show that pressure drop per row is independent of the number of rows in the bank with laminar flow. Equations (5-166) and (5-167) will predict the pressure drop within about ±25 per cent.

The validity of extrapolating Eq. (5-166) to pitch ratios larger than 1.50 is not known. The correlation of Gunter and Shaw (*loc. cit.*) can be used as an approximation for such cases.

For the laminar flow of non-Newtonian solutions across tube banks, see Adams and Bell [*Chem. Eng. Progr.*, 64, *Symp. Ser.* 82, 133–145 (1968)].

BEDS OF SOLIDS

Fixed Beds of Granular Solids. Pressure-drop data on the flow of fluids through beds of granular solids are not readily correlated because of the variety of granular materials and of their packing arrangement. For the flow of a single incompressible fluid through a bed of granular solids, the pressure drop or other flow characteristics can be predicted from the correlation given by Leva [*Chem. Eng.*, 56(5), 115–117 (1949), or "Fluidization," McGraw-Hill, New York, 1959]. In this correlation,

$$\Delta p = \frac{2 f_m G^2 L (1-\epsilon)^{3-n}}{D_p g_c \rho \phi_s^{3-n} \epsilon^3} \qquad (5\text{-}168)$$

where Δp = pressure drop, lb. force/sq. ft.; L = depth of bed, ft.; g_c = dimensional constant, 32.17 (lb.)(ft.)/(lb. force)(sec.²); D_p = average particle diameter, defined as the diameter of a sphere of the same volume as the particle, ft.; ϵ = voidage (fractional free volume), dimensionless; n = exponent, a function of the modified Reynolds number N'_{Re} given in Fig. 5-69, dimensionless; ϕ_s = shape factor of the solid, defined as the quotient of the area of a sphere equivalent to the volume of the particle divided by the actual surface of the particle, dimensionless; G = fluid superficial mass velocity based on empty chamber cross section, lb./(sec.)(sq. ft.); ρ = fluid density, lb./cu. ft.; f_m = friction factor, a function of N'_{Re} given in Fig. 5-69. The modified Reynolds number N'_{Re} is defined as

$$N'_{Re} = \frac{D_p G}{\mu} \qquad (5\text{-}169)$$

where μ = fluid viscosity, lb./(ft.)(sec.).

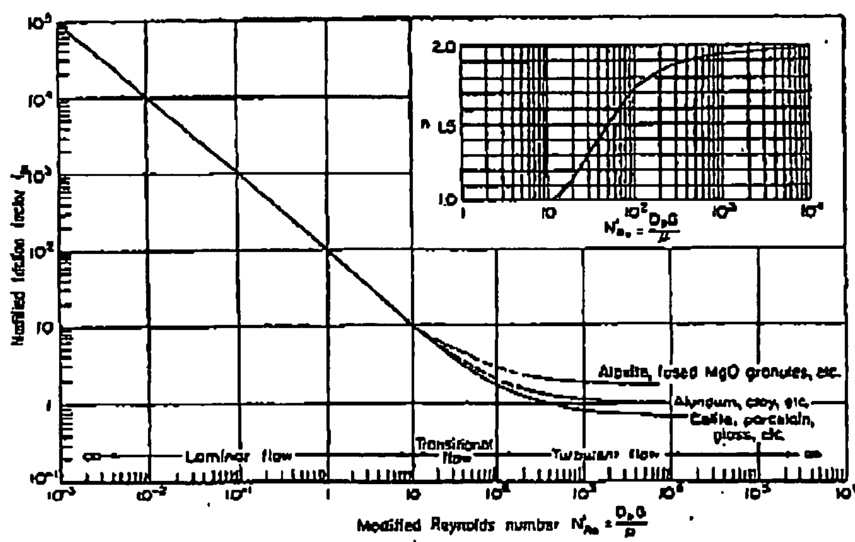

FIG. 5-69. Friction factor for beds of solids. (*Leva, "Fluidization," p. 49, McGraw-Hill, New York, 1959.*)